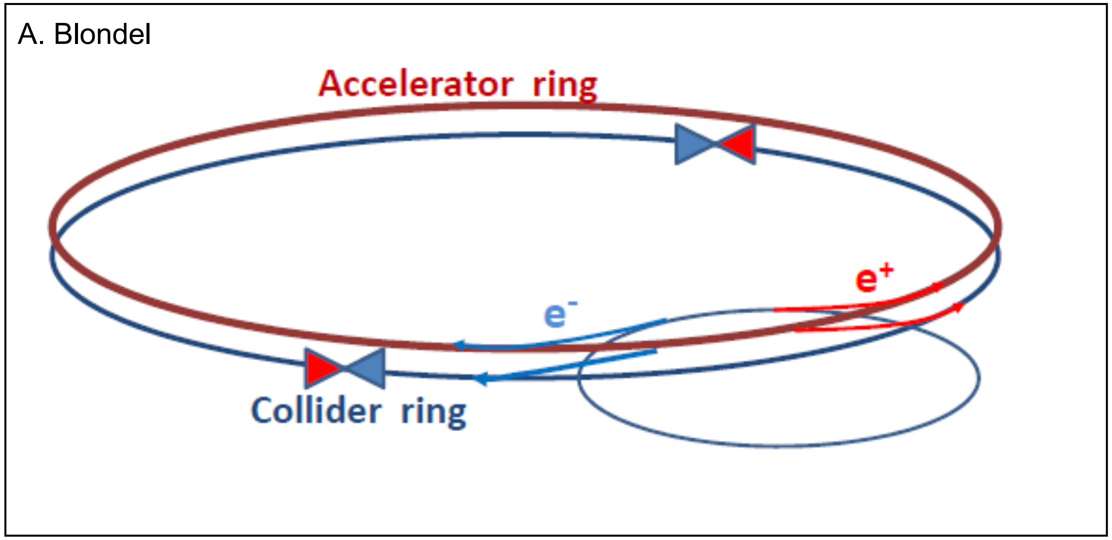
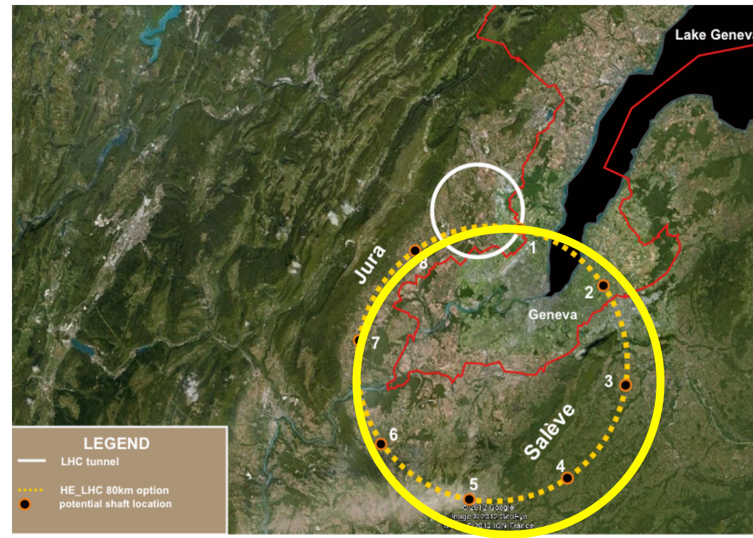
TLEP White Paper : Executive Summary

- TLEP : A first step in a long-term vision for particle physics
  - In the context of a global project



CERN implementation



J. Osborne and C. Waajer

- See Design Study Proposal at http://tlep.web.cern.ch/
- Most recent workshop 4-5 April 2013 (CERN) https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=240814
- Next workshop 25-26 July 2013 (FNAL)

Scientific Motivation

Today's situation

- A (very) Standard Higgs boson

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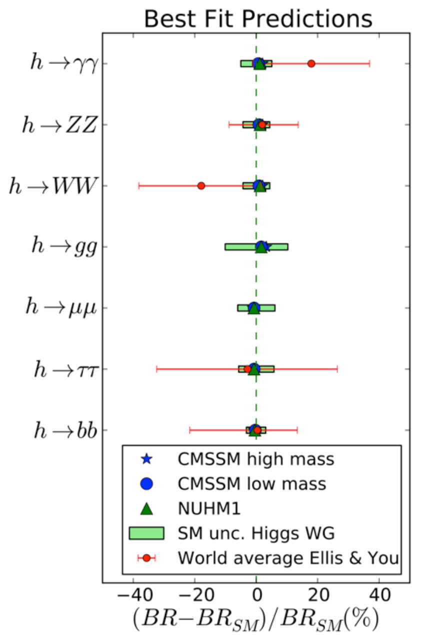
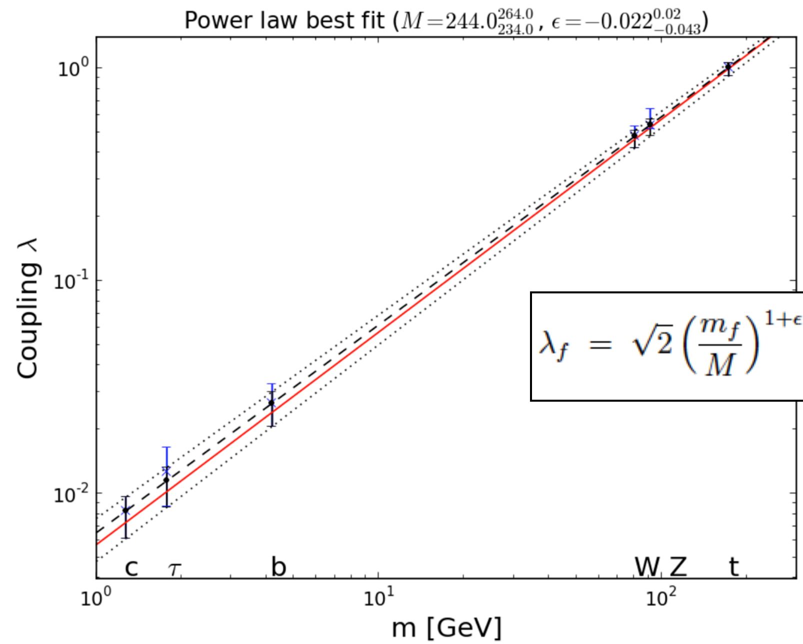




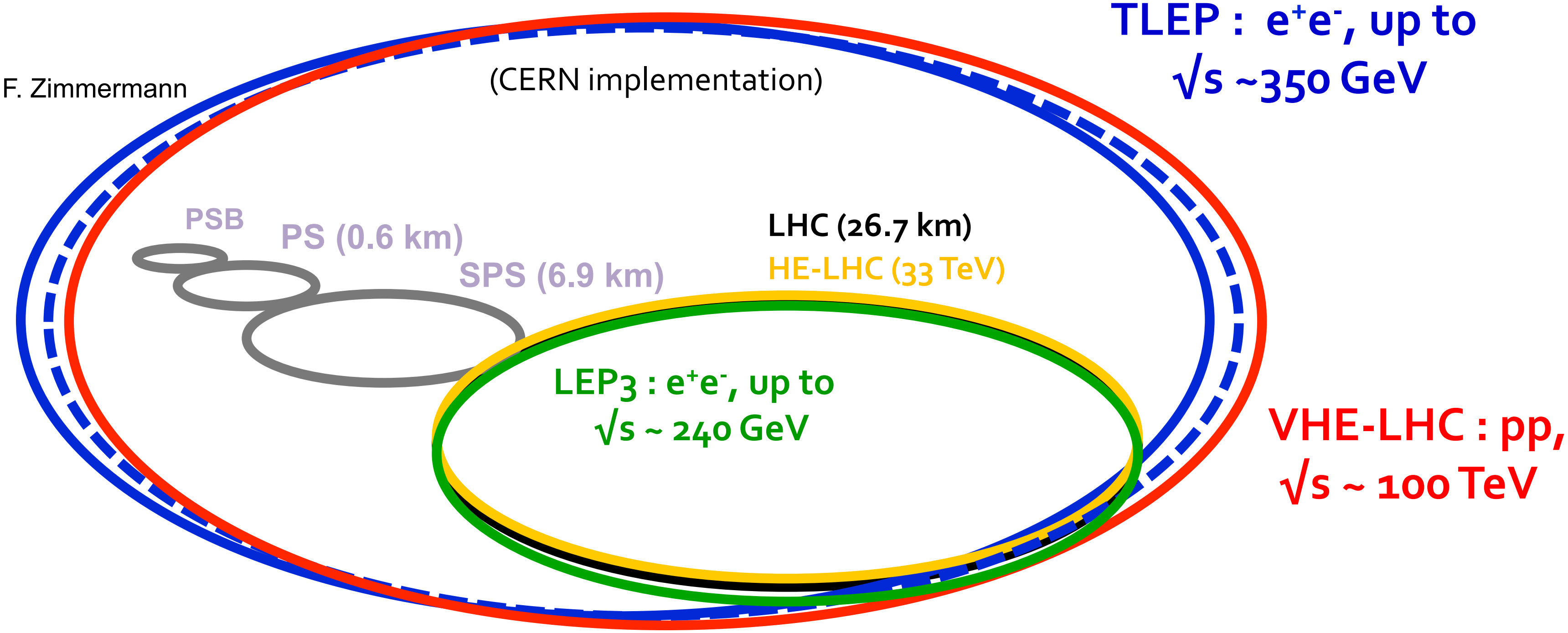
$$\lambda_f = \sqrt{2}\left(\frac{m_f}{M}\right)^{1+\epsilon}, \quad g_V = 2\left(\frac{m_V^{2(1+\epsilon)}}{M^{1+2\epsilon}}\right)$$

- No new physics all the way to several 100's GeV (SUSY) or more
  - Next run at 14 TeV will extend the coverage to ~500 GeV (SUSY) or more
    - ➨ Very strong incentive to look for multi-TeV new Physics
    - ➨ Linear Colliders with √s = o(TeV) do not cover this Physics case

What else, then ?

What next ?

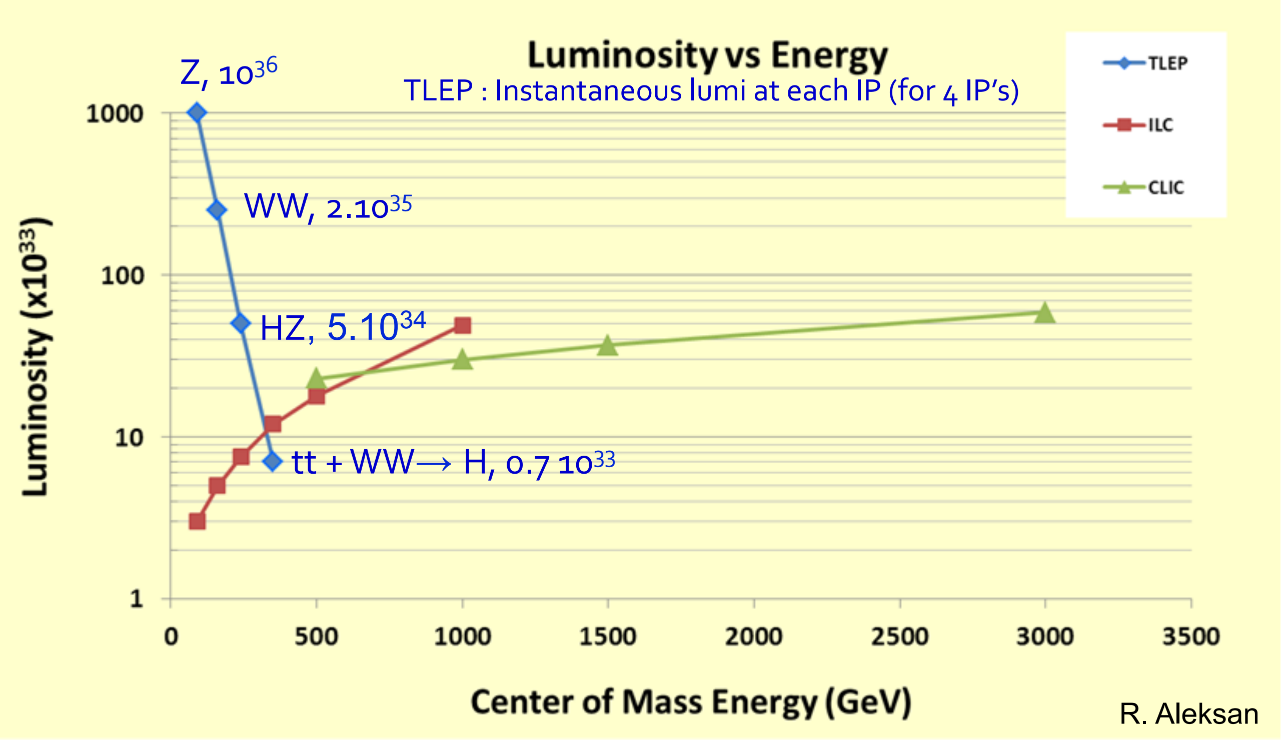
- **Build a new 80-100 km circular tunnel :**



- TLEP Physics case : Precision measurements sensitive to multi-TeV New Physics
  - TeraZ ($\sqrt{s}$~m_Z), MegaW ($\sqrt{s}$~$2m_W$), Higgs Factory ($\sqrt{s}$~240 GeV), top ($\sqrt{s}$~350 GeV)
    - With luminosity 20-1000 × larger than projects of similar timescale and cost
- Followed by VHE-LHC : Direct search for New Physics in the 10-100 TeV range
  - $\sqrt{s}$ ~ 100 TeV with 20T magnets
    - Also allows the HHH coupling to be measured to a few %

Luminosity at TLEP (1)

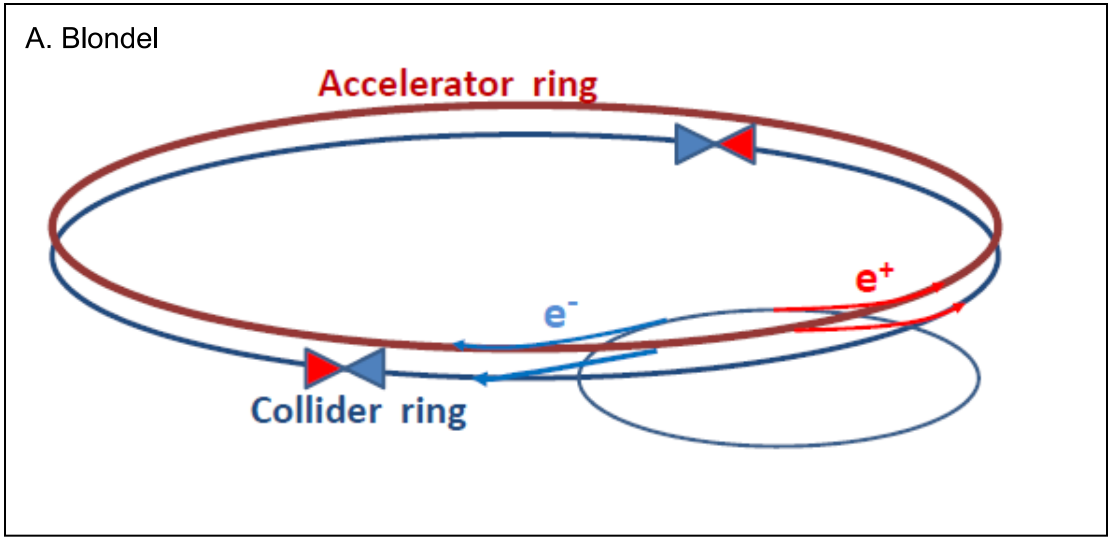
- **Luminosity increases when √s decreases at circular colliders**
  - By optimal use of the RF power to collide more bunches when SR decreases ($1/E^4$)



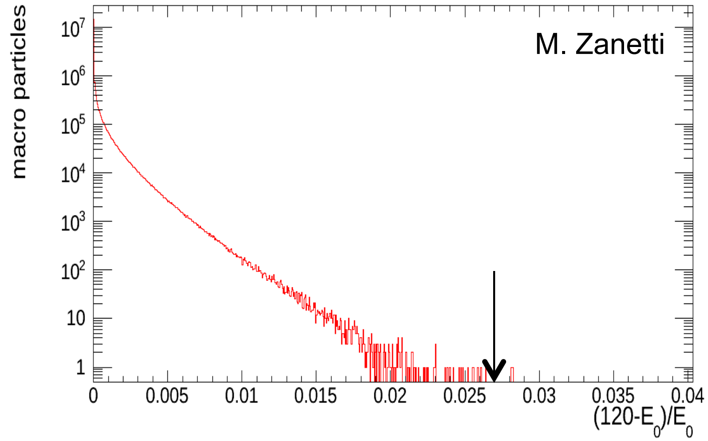
- And circular colliders can have multiple IP's
  - ➨ e.g., four detectors at LEP : multiply integrated luminosity by a factor four
- Ultimate precision measurements are therefore made possible at circular colliders

Luminosity at TLEP (2)

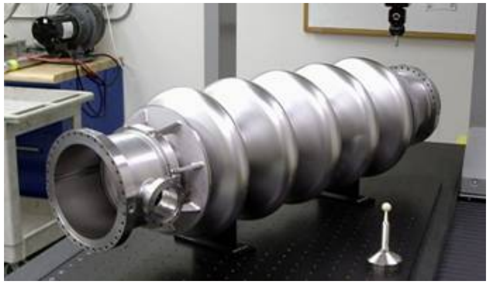
- **Luminosity achieved by reducing the vertical β***
  - From 5 cm (LEP2) to 1 mm (TLEP)
    - Note : 0.3 mm soon to be realized at SuperKEKB
  - Vertical beam size ~ 200 nm
    - Note : 1 to 5 nm for Linear Colliders
      - ➨ Hence negligible Beamstrahlung for Physics, beam energy well known
- **At these luminosities, beam lifetime ~ 15 minutes (Bhabha scattering)**
  - Solution : continuous top-up injection, as at PEP-II
    - Note : Soon to be realized at Super-KEKB, beam lifetime ~ 5 minutes



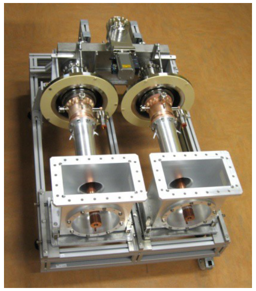
Challenges (A subset)



- **Beamstrahlung**
  - Radiating $e^{\pm}$ pushed outside the acceptance
    - Reduces the beam lifetime significantly
  - Need to design an achromatic optics at the IPs
    - with 2-3% momentum acceptance
- **Efficient RF system**
  - Need 12 GeV/turn at 350 GeV
    - ~900 m of SC RF cavities @ 20 MV/m
      - LEP2 had 600 m at 7 MV/m
  - Very high power : up to 200 kW / cavity in the collider ring
    - Power couplers similar to ESS – 700-800 MHz preferred
- **Small vertical emittance**
  - Can further reduce beamstrahlung by minimizing $\varepsilon_y/\varepsilon_x$
    - Aim is to reach 0.1% (LEP2 had 0.4%)
- **Operation at the Z pole**
  - 2625 bunches : e^+ source, impedance effects, parasitic collisions
    - May need two rings designed to separate e^+ and e^- beams



BNL 5-cell 700 MHz cavity



RF Coupler (ESS/SPL)

Physics case as a Higgs Factory (1)

- **Number of Higgs bosons produced at $\sqrt{s}$ = 240-250 GeV**

	ILC-250	LEP3-240	TLEP-240
Lumi / IP / 5 years	250 fb^{-1}	500 fb^{-1}	2.5 ab^{-1}
# IP	1	2 - 4	2 - 4
Lumi / 5 years	250 fb^{-1}	1 - 2 ab^{-1}	5 - 10 ab^{-1}
Beam Polarization	80%, 30%	–	–
$L_{0.01}$ (beamstrahlung)	86%	100%	100%
Number of Higgs	70,000	400,000	2,000,000
Upgradeable to	ILC 1TeV CLIC 3 TeV ?	HE-LHC 33 TeV	VHE-LHC 100 TeV

- **In a given amount of time, Higgs coupling precisions scale like**
  - e.g., for g_{HZZ} : 1.5% for ILC : 0.65% for LEP3 : 0.2% for TLEP

Physics case as a Higgs Factory (2)

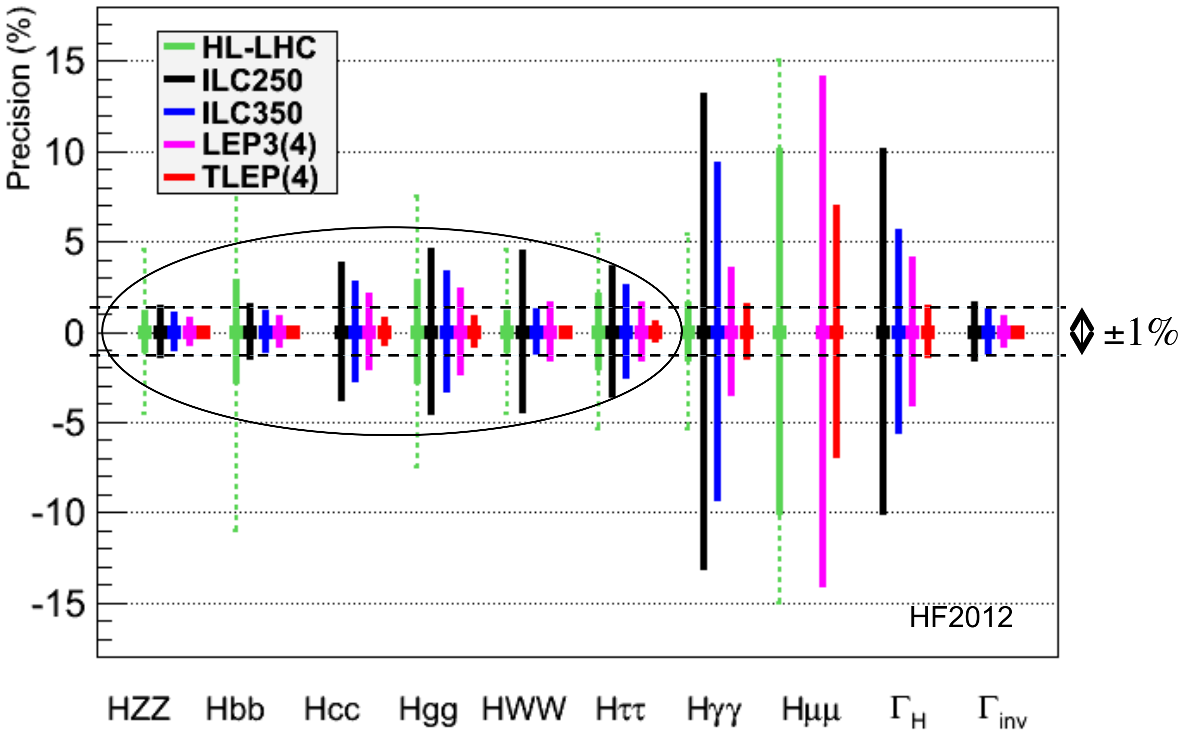
Summary of the ICFA Higgs Factory Workshop (FNAL, Nov. 2012)

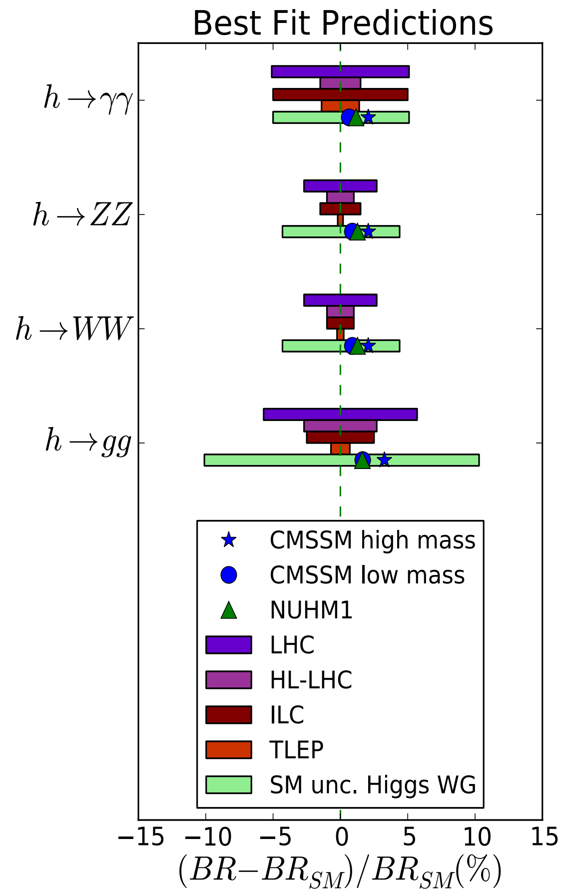
Accelerator → Physical Quantity ↓	**LHC** 300 fb^{-1} /expt	**HL-LHC** 3000 fb^{-1} /expt	**ILC** 250 GeV 250 fb^{-1} 5 yrs	**Full ILC** 250+350+ 1000 GeV 5yrs each	**CLIC** 350 GeV (500 fb^{-1}) 500 GeV (500 fb^{-1}) 1.4 TeV (2 ab^{-1}) 5 yrs each	**LEP3, 4 IP** 240 GeV 2 ab^{-1} (*) 5 yrs	**TLEP, 4 IP** 240 GeV 10 ab^{-1} 5 yrs (*) 350 GeV 1.4 ab^{-1} 3 yrs (*)
N_H	1.7×10^7	1.7×10^8	6×10^4 ZH	10^5 ZH 1.4×10^5 Hνν		4×10^5 ZH	2×10^6 ZH
m_H (MeV)	100	50	35	35	~70	26	7
$\Delta\Gamma_H / \Gamma_H$	--	--	10%	3%	6%	4%	1.3%
$\Delta\Gamma_{inv} / \Gamma_H$	Indirect (30%?)	Indirect (10% ?)	1.5%	1.0%	--	0.35%	0.15%
$\Delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$	6.5 – 5.1%	5.4 – 1.5%	--	5%	N/A	3.4%	1.4%
$\Delta g_{Hgg} / g_{Hgg}$	11 – 5.7%	7.5 – 2.7%	4.5%	2.5%	N/A	2.2%	0.7%
$\Delta g_{Hww} / g_{Hww}$	5.7 – 2.7%	4.5 – 1.0%	4.3%	1%	1%	1.5%	0.25%
$\Delta g_{HZZ} / g_{HZZ}$	5.7 – 2.7%	4.5 – 1.0%	1.3%	1.5%	1%	0.65%	0.2%
$\Delta g_{HHH} / g_{HHH}$	--	< 30% (2 expts)	--	~30%	~20%	--	--
$\Delta g_{H\mu\mu} / g_{H\mu\mu}$	< 30%	< 10%	--	--	15%	14%	7%
$\Delta g_{H\tau\tau} / g_{H\tau\tau}$	8.5 – 5.1%	5.4 – 2.0%	3.5%	2.5%	3%	1.5%	0.4%
$\Delta g_{Hcc} / g_{Hcc}$	--	--	[illegible].7%	2%	4%	2.0%	0.65%
$\Delta g_{Hbb} / g_{Hbb}$	15 – 6.9%	11 —2.7%	1.[illegible]%	1%	2%	0.7%	0.22%
$\Delta g_{Htt} / g_{Htt}$	14 – 8.7%	8.0 – 3.9%	--	15%	3%	--	30%

Best precision

Physics case as a Higgs Factory (3)

- **Need sub-percent precision for a sensitivity to multi-TEV New Physics**
  - Compare (LHC), HL-LHC, ILC, (LEP3), TLEP





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- **Summary : TLEP reaches the needed accuracy**
  - ➨ **Much theoretical work also needed**

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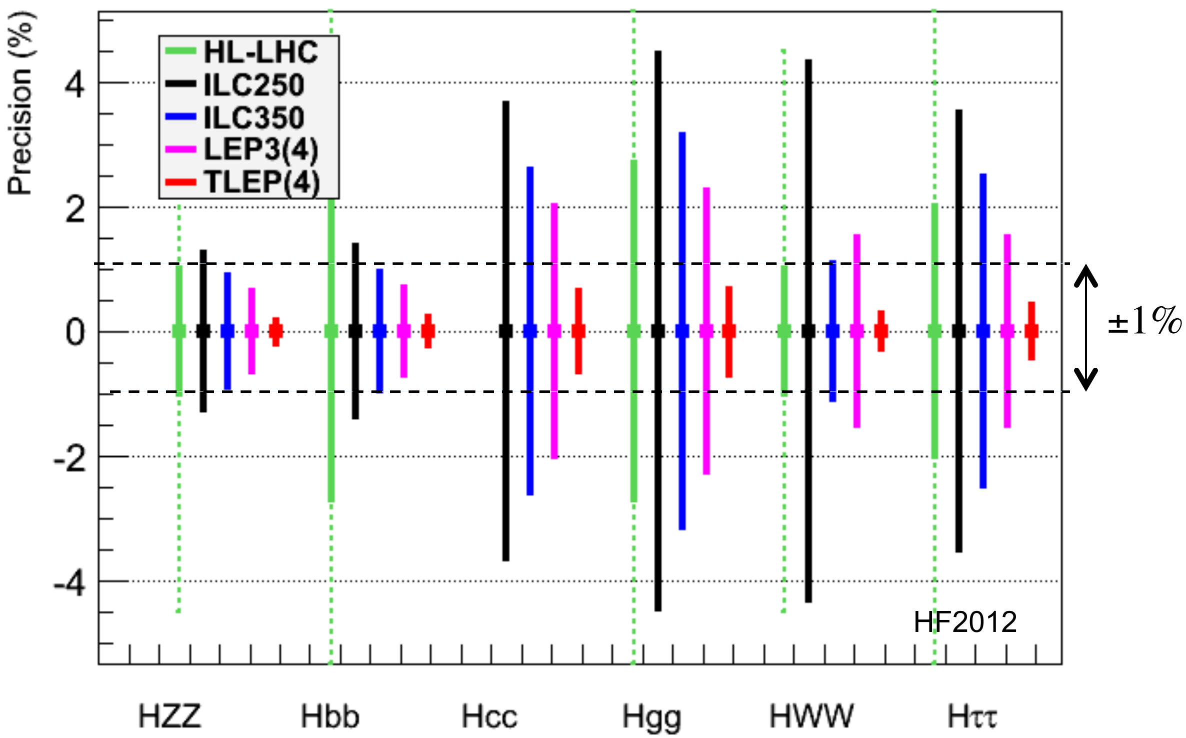

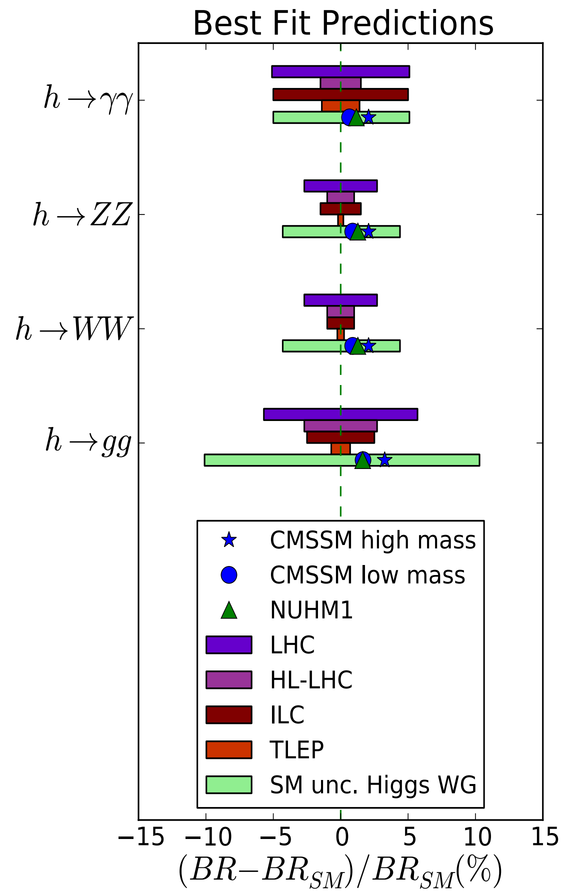

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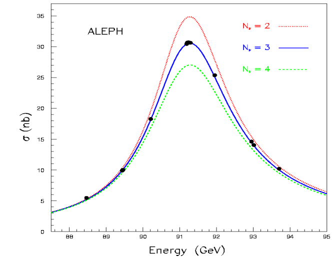
Impact of TeraZ and MegaW (1)

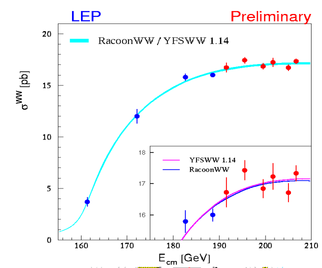
- **Revisit and improve the LEP precision measurements**
  - **TLEP can do the entire LEP1 physics programme in 5 minutes**

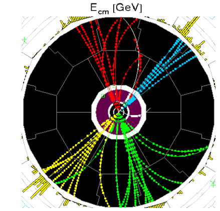
	LEP	ILC	LEP3	TLEP
$\sqrt{s} \sim m_Z$	MegaZ	GigaZ	~TeraZ	TeraZ
Lumi ($cm^{-2}s^{-1}$) #Z / year Polarization **vs LEP1**	Few 10^{31} 2×10^7 no **1**	Few 10^{33} Few 10^9 easy **~5-10**	Few 10^{35} Few 10^{11} yes (T, L) **~50**	10^{36} 10^{12} yes (T,L) **~100**
$\sqrt{s} \sim 2m_W$				
Lumi ($cm^{-2}s^{-1}$) Lumi / IP / year **Error on m_W**	Few 10^{31} 10 pb^{-1} **220 MeV**	Few 10^{33} 50 fb^{-1} **7 MeV**	5×10^{34} 500 fb^{-1} **0.7 MeV**	2.5×10^{35} 2.5 ab^{-1} **0.4 MeV**
$\sqrt{s} \sim$ 200-250 GeV				
Lumi ($cm^{-2}s^{-1}$) Lumi / IP / 5 years **Error on m_W**	10^{32} 500 pb^{-1} **33 MeV**	5×10^{33} 250 fb^{-1} **3 MeV**	10^{34} 500 fb^{-1} **1 MeV**	5×10^{34} 2.5 ab^{-1} **0.4 MeV**

Asymmetries, Lineshape



WW threshold

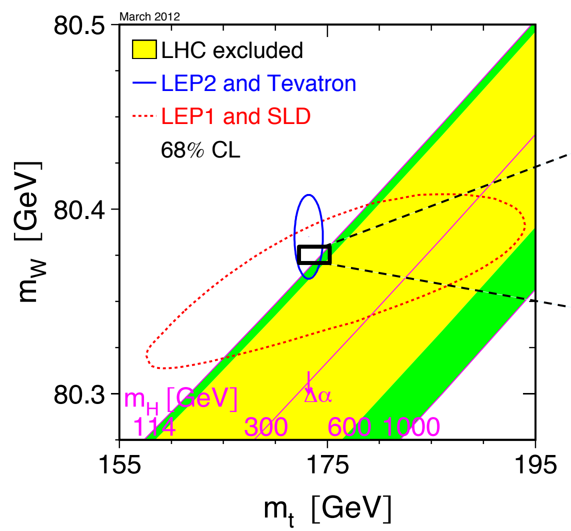


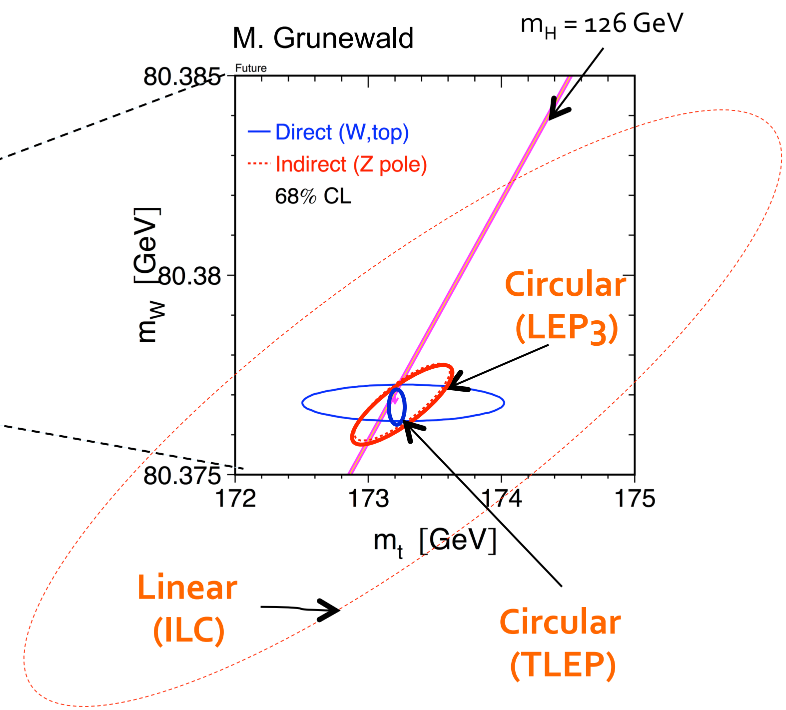


- **Important : Polarization up to the WW threshold with TLEP**
  - **Very precise beam energy determination (10 keV) : unique to circular colliders**
    - ➨ **Measure m_Z, Γ_Z to < 0.1 MeV, m_W to < 1 MeV, $\sin^2\theta_W$ to 2.10^{-6} from A_{LR}**

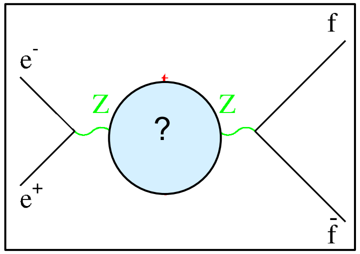
Impact of TeraZ and MegaW (2)

- **Case 1 : Only SM physics in EW Radiative Corrections – Stringent SM Closure test**
  - **Set stringent limits on weakly interacting new physics (m_H, m_W and m_{top} known)**
    - **Much theoretical work also needed**





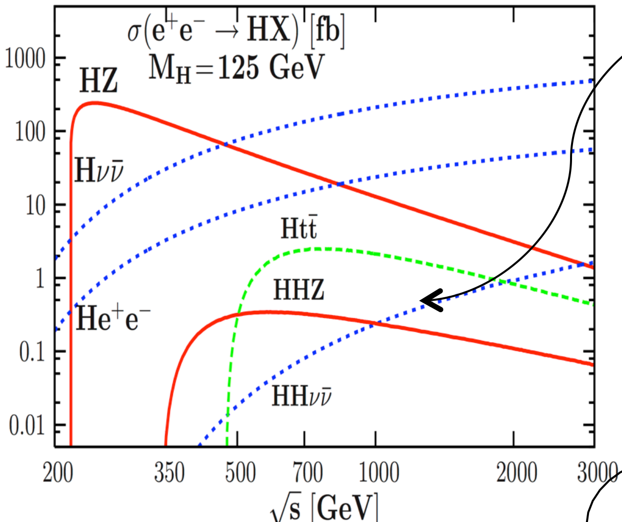
- **Case 2 : Some weakly interacting new physics in the loops ?**
  - **Will cause inconsistency between the various observables**
    - **Become sensitive to multi-TeV WINP**
      - ➨ **LEP1 was sensitive to ~ 200 GeV (m_{top})**

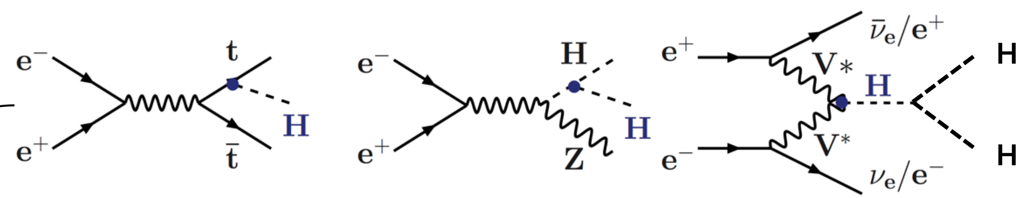


Physics case of the energy upgrades (1)

- **All existing proposals have access to larger $\sqrt{s}$**
  - To discover New Physics in a direct manner
  - To measure more difficult Higgs couplings : g_{Htt} and g_{HHH}
    - ILC350 can be upgraded to ILC500/ILC1TeV, or even to CLIC (3 TeV) [?]
    - LEP3 can be upgraded to (or preceded by) HE-LHC (33 TeV)
    - TLEP can be upgraded to VHE-LHC (100 TeV)

Cross sections in e^+e^- collisions





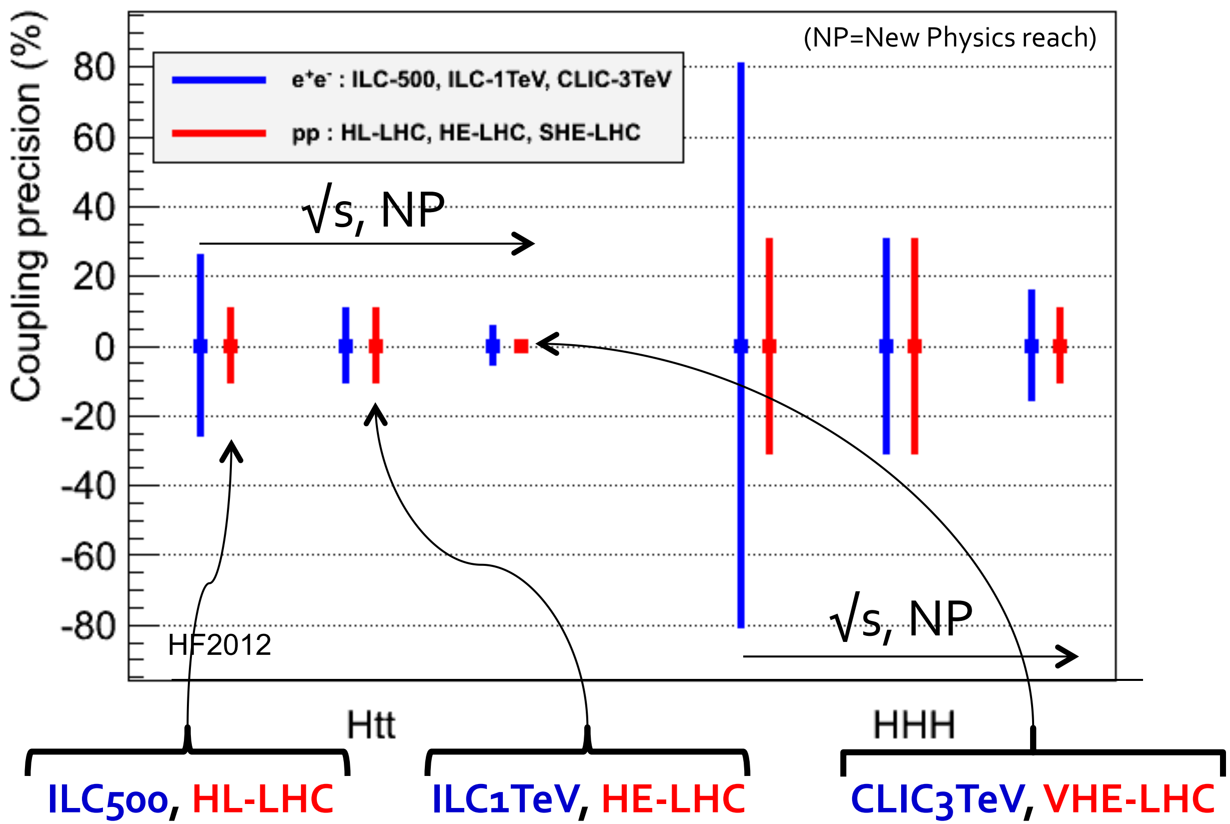
M. Mangano

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42

Cross sections in pp collisions

Physics case of the energy upgrades (2)

- **Summary for Htt and HHH couplings**
  - Other Higgs couplings benefit only marginally from high energy



- **TLEP + VHE-LHC looks like a winning team**

Conclusions

- We believe TLEP to be the best complementary machine to LHC
  - Higgs properties precision measurements; Stringent test of the SM closure.
- TLEP is based on a well-known technology
  - Supported by much progress in e^+e^- circular factories for 20 years (and counting)
    - LEP, LEP2, (super) b factories, synchrotron light sources
  - Based on this experience, luminosity, power and cost predictions will be reliable
- It is a first step in a long-term vision for high-energy physics
  - Many synergies with VHE-LHC (pp collisions at 100 TeV)
    - Tunnel, accelerator, experiments, physics
- The design study is starting up as we speak, supported by CERN strategy
  - Join us at http://tlep.web.cern.ch
- The goal is to have a technically-ready proposal by 2018
  - So that the community can take a fully-informed decision
    - with the LHC Run2 results at $\sqrt{s}$ = 13-14 TeV in hand
- We aim for physics in 2030